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Ionospheric Monitoring and Specification Utilizing Data From the Defense Meteorological Satellite Program

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14. ABSTRACT

Following the November 2006 launch of the DMSP F17 spacecraft, work was begun at the UTD on the development of ground software for the routine production of geophysical data records from the F17 SSIES-3 instrument package data that is provided to UTD by the scientists at the Air Force Research Laboratory (AFRL). The SSIES-3 sensors include the Retarding Potential Analyzer (RPA), the Drift Meter (DM), the Scintillation Meter (SM), the Electron Sensor (ES), and the Plasma Plate (PP). The first task performed during this contract period was the identification and remediation of single-event upsets occurring in the South Atlantic anomaly region. The primary accomplishment this year was the development of an integrated software package to routinely convert the raw data to time-tagged geophysical parameters. A basic production level software package has been created that processes the RPA, DM, SM, and ES sensor data. The PP algorithms are not yet reliably functioning. While the RPA algorithm is functioning well, it is expected, based on past experience, that as larger volumes of data are processed, further refinement will be required.

15. SUBJECT TERMS

Ionospheric monitoring, Near-Earth space environment, DMSP Satellites, Spectral Sensor for Ions, Electrons and Scintillation (SSIES), Ion drift velocity

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1. INTRODUCTION

Following the November 2006 launch of the Defense Meteorological Satellite Program (DMSP) F17 spacecraft, work was begun at the University of Texas at Dallas (UTD) on the development of ground software for the routine production of geophysical data records from the F17 SSIES-3 instrument package data that was provided to UTD by the scientists at the Air Force Research Laboratory (AFRL). The SSIES-3 sensors include the Retarding Potential Analyzer (RPA), the Drift Meter (DM), the Scintillation Meter (SM), the Electron Sensor (ES), and the Plasma Plate (PP). Taken together, these sensors provide extensive data on the state of the ambient thermal plasma. In addition, UTD has provided support to AFRL as needed for the interpretation and maintenance of these instruments. A brief description of each of the major tasks performed during this contract period follows.

2. EFFECT OF VEHICLE POTENTIAL ON ION DRIFT

The Drift Meter (DM) sensor on the DMSP Special Sensors-Ions, Electrons, and Scintillation (SSIES) thermal plasma analysis package provides the horizontal and vertical drifts perpendicular to the satellite velocity vector. When He^+ or H^+ ions represent a significant fraction of the total ambient ion density, the instrument performance is degraded. The fraction of light ions that constitutes enough to degrade the performance of the instrument depends on the spacecraft and the ionospheric conditions, but is around 5%. Starting in 1998, a retarding grid in front of the DM aperture, called the DREP, was set at +2 V on all of the operational spacecraft. H^+ has an energy of 1.2 eV at the spacecraft velocity of 7.5 km/s while O^+ has an energy of 4.8 eV, so most of the light ions are repelled while the O^+ ions are allowed through. However, it was recently discovered that the DMSP F15 DM DREP voltage was set at 0 V, seriously degrading the data quality when He^+ or H^+ ions were present in significant quantities. It was found that when the power on the F15 satellite is cycled, the DREP voltage is returned to 0 V. Tests were subsequently run, operating the DMSP F15 and F16 spacecraft with the DREP repeller grid on and with it off, clearly showing the improvement in the data quality with the grid on. The DMSP F15, F16, and F17 satellites now all have the DM DREP voltages set to 1 or 2 V. The following discussion reports UTD's efforts to identify the problem and suggest the solution.

2.1. Study Results

To investigate the efficacy of the DM DREP in improving the data quality, we examined the DMSP F12, F13, F14, and F15 DM data during periods and in locations when and where the drifts were expected to be near 0, but where there could be a significant amount of light ions present. These were periods when there was no geomagnetic activity, determined by the Kp geomagnetic indices, and identified as the three quietest days in each of several months over a 5-year period. The locations were selected as between 45° and 50° magnetic latitude (MLAT), well below the auroral zone and above the equator where significant ion drifts were expected to be present. We performed the study for the period from 1997 to 2005. Figure 1 shows the results for the DMSP F13 spacecraft from January 1998 – before the DREP was set to 2 V – and January 1999 – after the DREP was set. Plotted is the ratio of H^+ to O^+ (measured by the RPA sensor) versus the ion drifts. The panels on the left side are for the horizontal drift and the panels on the right side are for the vertical drift, while the top panels are from 1998 and the bottom panels are from 1999. Red indicates data acquired in the northern hemisphere while blue indicates data acquired in the southern hemisphere. The difference is clear, with major excursions of the ion drifts from near 0 in 1998 above an H^+/O^+ ratio of about 0.1, and little excursions from 0 in 1999. Also, the (smaller) excursions in 1999 occur at a larger ratio, closer to 0.5 or so.

Figure 2 shows the results for the DMSP F13 and F15 satellites in January 2001, in the same format as Figure 1. The top panels show the data from F13 and the bottom panels show the data from F15. It is clear that the DREP is set and working on F13 but not on F15, particularly evident in the vertical (VZ) measurements. It is even more evident in the results from July 2001, as shown in Figure 3. We found a strong seasonal variation in the light ion effect, apparent in the comparison of Figure 2 and Figure 3. This is the natural result of a change in ionospheric conditions throughout the year; the light ion effect is dependent not only on the H^+/O^+ ratio, but on the total ion concentration. For instance, if the O^+ density is below about 5 X 10^{-3} cm^{-3}, the DM measurements are degraded due to lack of signal. This is evident in Figure 4, which shows the O^+ density plotted versus the horizontal and vertical drifts. The data does not organize as well as when the H^+/O^+ ratio is plotted, but it is clear that it is degraded when the density goes below about 5 X 10^{-3} cm^{-3}. For completeness, we show the results from January 2004 in Figure 5. The results are similar to those seen in 2001.

2.2. SSIES-3 Test

The SSIES instruments on DMSP F16 and F17 are an updated design, called the SSIES-3. To test the effectiveness of the DREP for F16, a test was run on the DMSP F15 and F16 satellites where the DREP was switched on and off on August 24 and 25, 2005. The results of the test are shown in Figures 6 and 7, in the same format as Figure 1. The F15 data is plotted in Figure 6 with the top panels showing the results when the DREP was on and the bottom panels showing when the DREP was off. Note that there was some geomagnetic activity on these days leading to ion drifts larger than seen during the previous studies where the study periods were selected for lack of geomagnetic activity. However, there are clear differences in the DREP on and DREP off data, particularly evident in the vertical drifts.

Figure 7 shows the test results for F16. The SSIES-2 RPA H^+ and O^+ data from F13 and F15 were produced by the UTD analysis software while the F16 SSIES-3 RPA data were produced by the operational software at AFRL. The UTD software was developed and refined over several years and provides a better solution to the current-voltage curves derived from the RPA data than the operational software. The operational software is unable to provide the H^+ density if the H^+/O^+ ratio is less than about 0.2 while the UTD software can provide H^+ density to H^+/O^+ ratios less than 0.01. This is clearly evident in the figures. Thus, there are only data for F16 at H^+/O^+ ratios above 0.2.

However, there are indications, particularly in the vertical drifts, that the data quality is improved with the DREP on. Further studies of the F16 data show that the data quality is improved with the DREP on.

2.3. Conclusion

It is clear that setting the DREP significantly improved the quality of the data when the H^+ density is a significant fraction of the total density. Thus, the DREP voltage of the drift meters on F15 and F16 were changed to 2 V as of 18:53 UT and 18:22 UT, respectively, on October 5, 2005. Unfortunately, it was subsequently discovered that the DREP on F15 was set back to 0 V on equatorial reset and on F16 set back to 0 V on restart. Finally, on March 26, 2007, the DREPs on F16 and F17 were set to turn on after each restart command and on May 3, 2007, the F15 DREP was set to turn on after each reset.

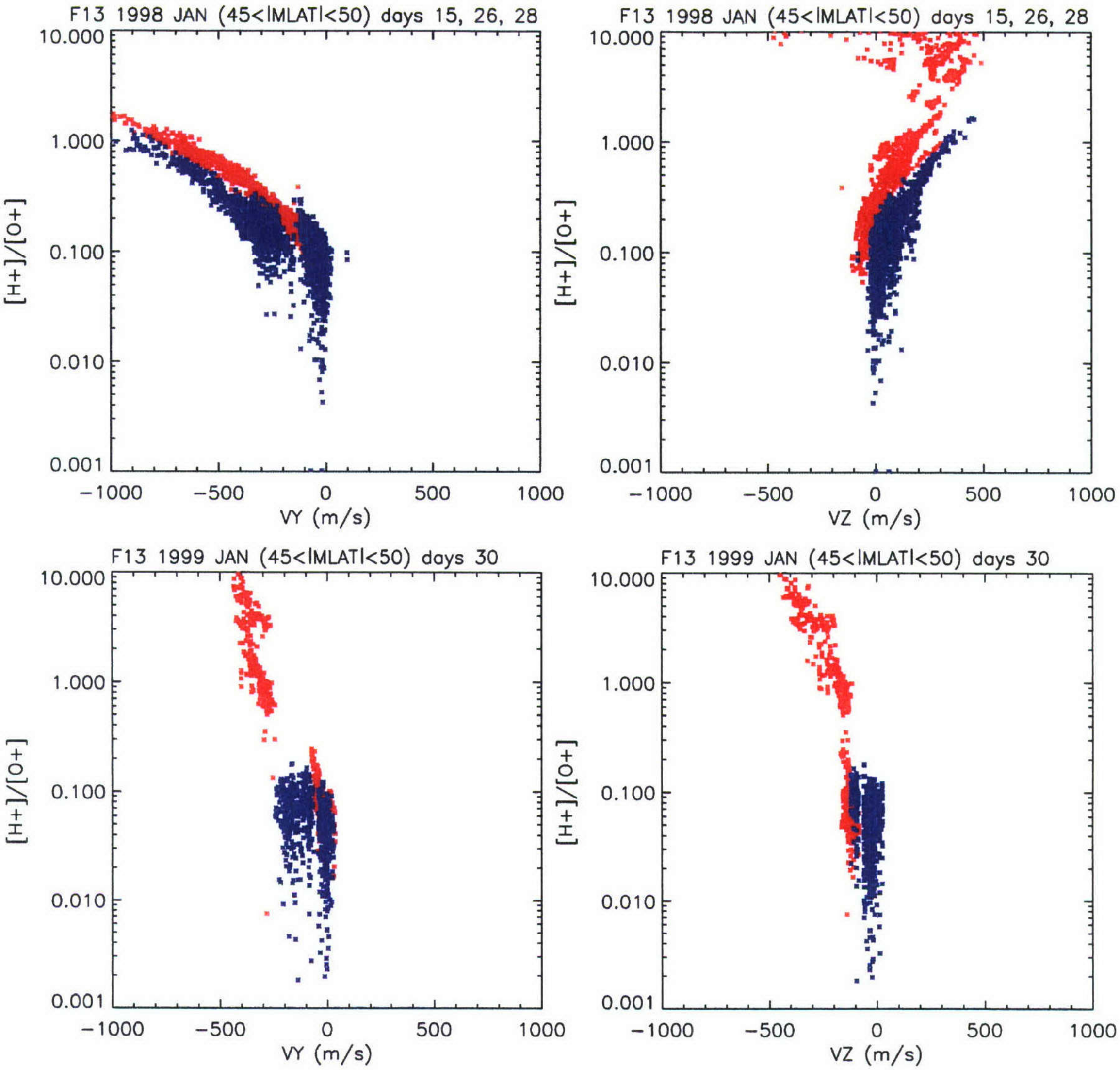

Figure 1. The ratio of H^+ to O^+ versus the horizontal (left) and vertical (right) ion drifts measured on F13. The top panels are from January 1998 and the bottom panels are from January 1999. Red indicates data acquired in the northern hemisphere while blue indicates data acquired in the southern hemisphere.

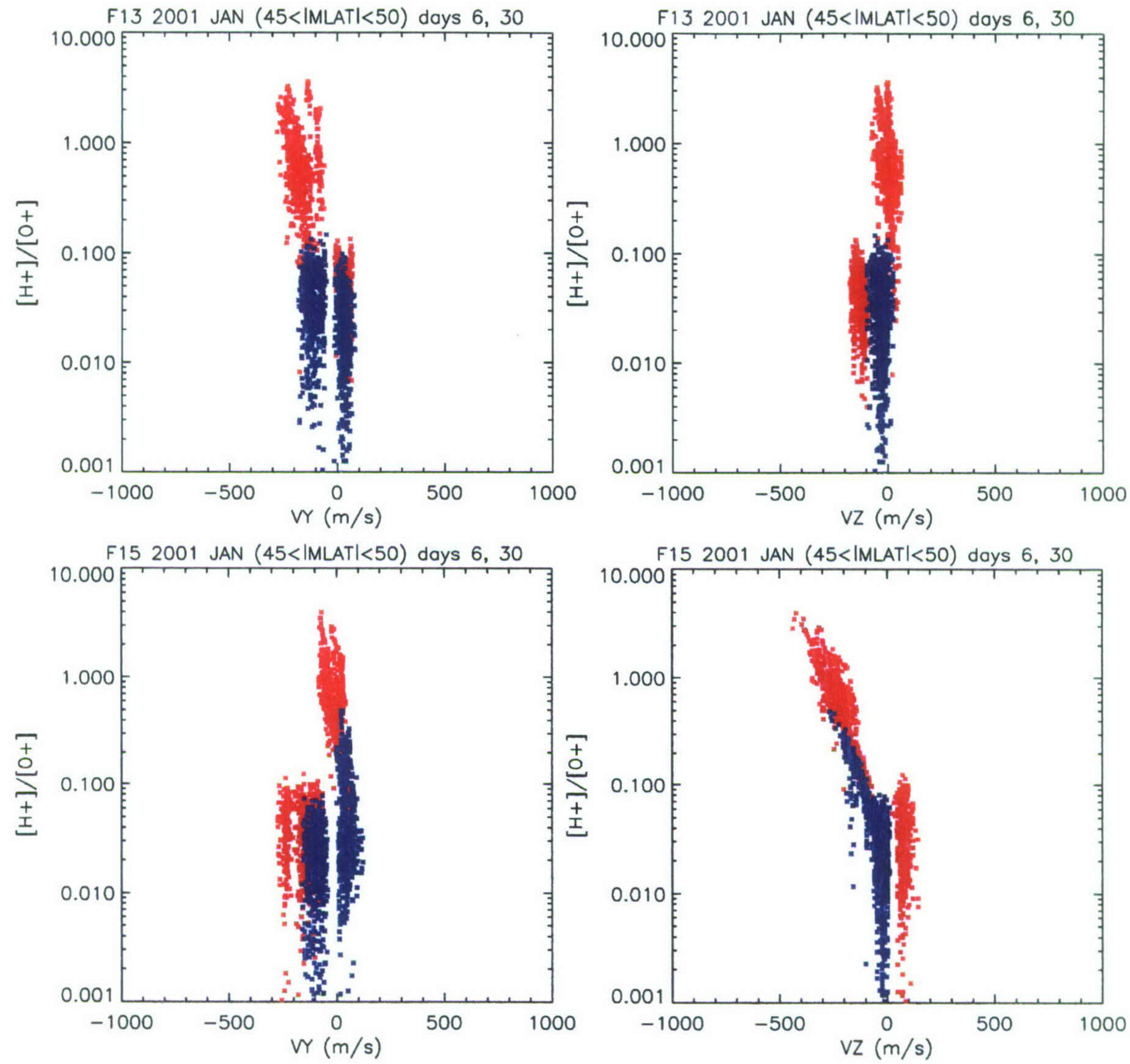

Figure 2. The ratio of H^+ to O^+ versus the ion drifts for F13 (top) and F15 (bottom) from January 2001 in the same format as Figure 1.

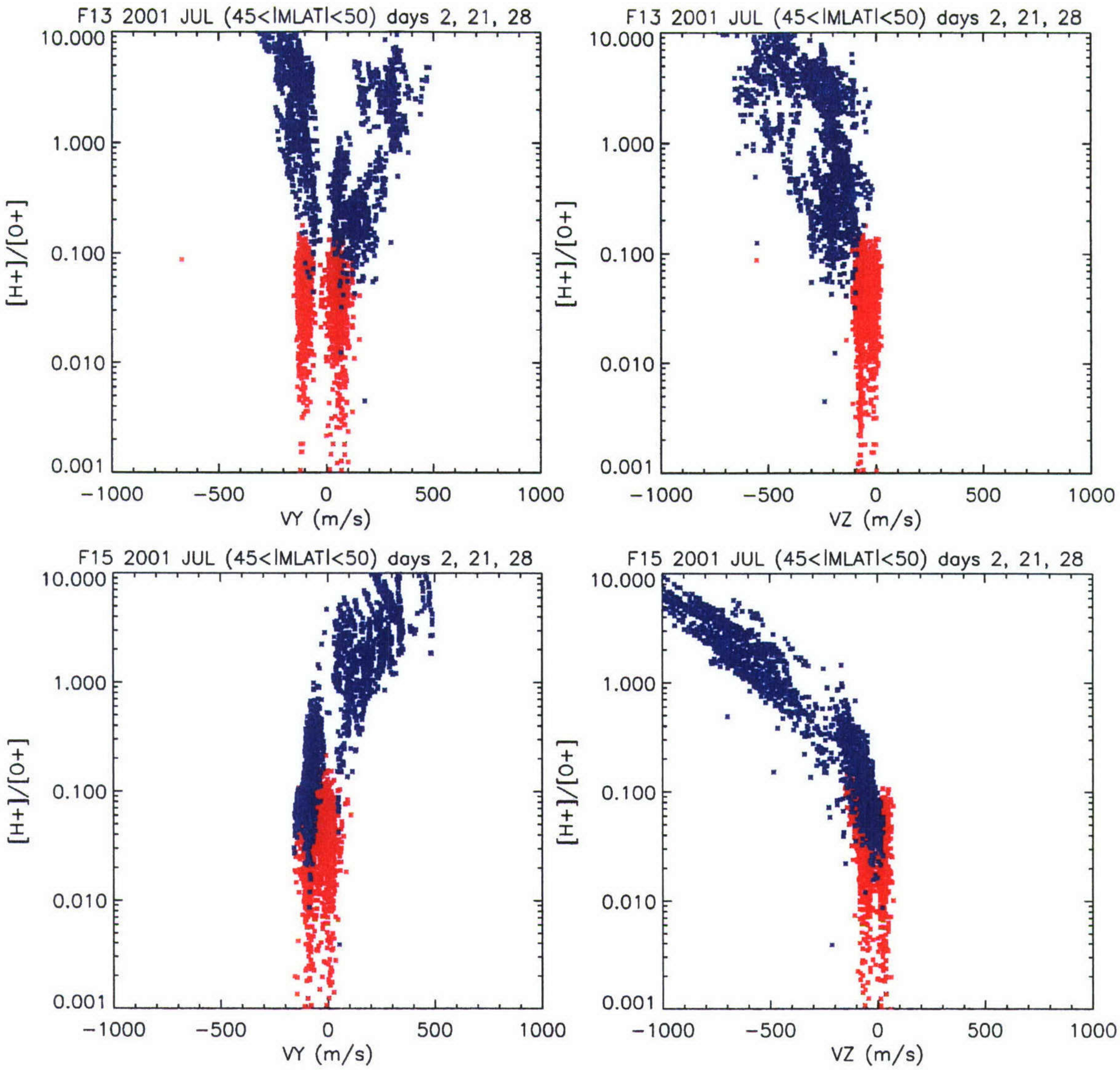

Figure 3. The ratio of H^+ to O^+ versus the ion drifts for F13 (top) and F15 (bottom) from July 2001 in the same format as Figure 1.

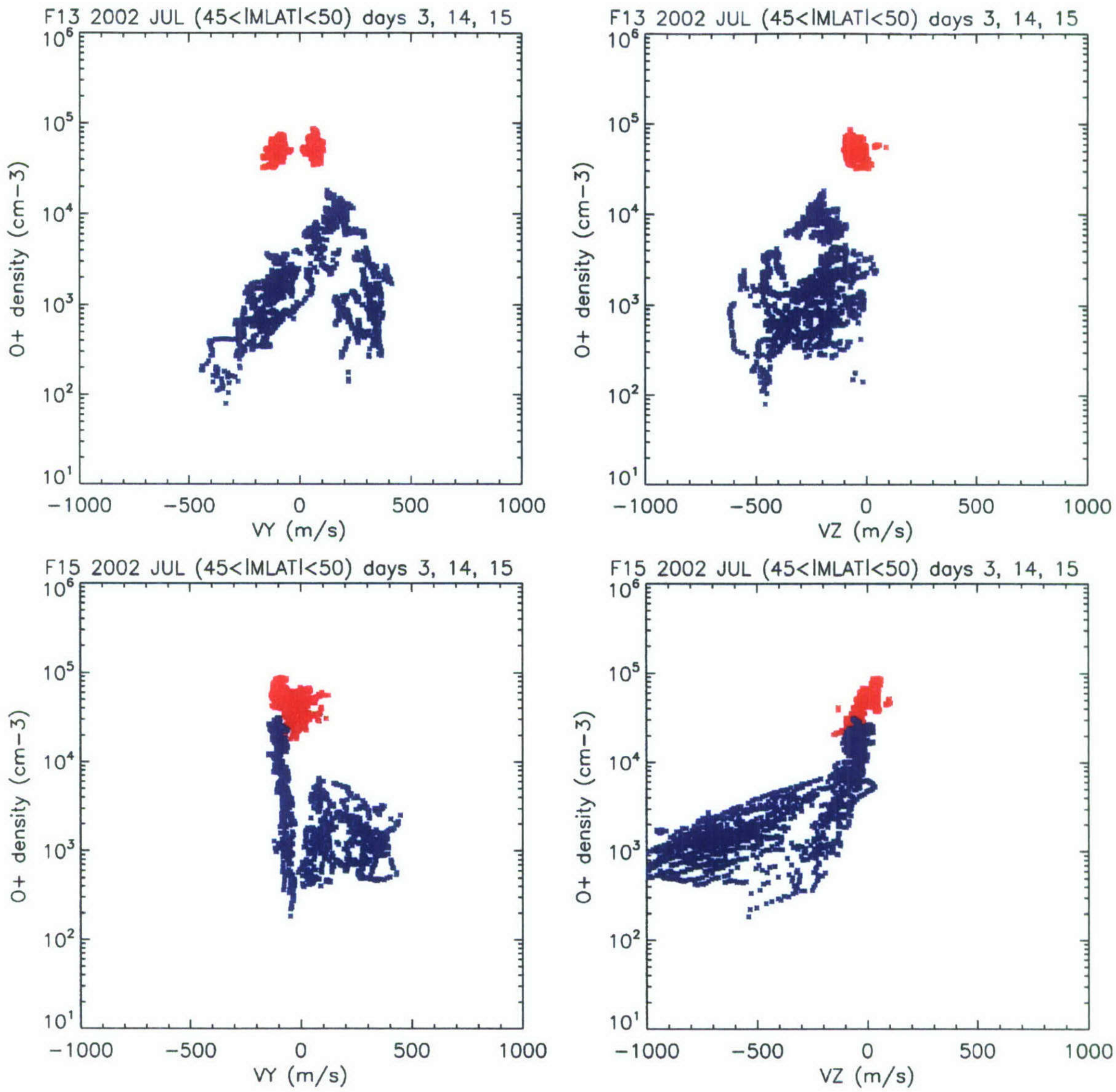

Figure 4. The O^+ density versus the ion drifts for F13 (top) and F15 (bottom) from July 2002 in a similar format to Figure 1.

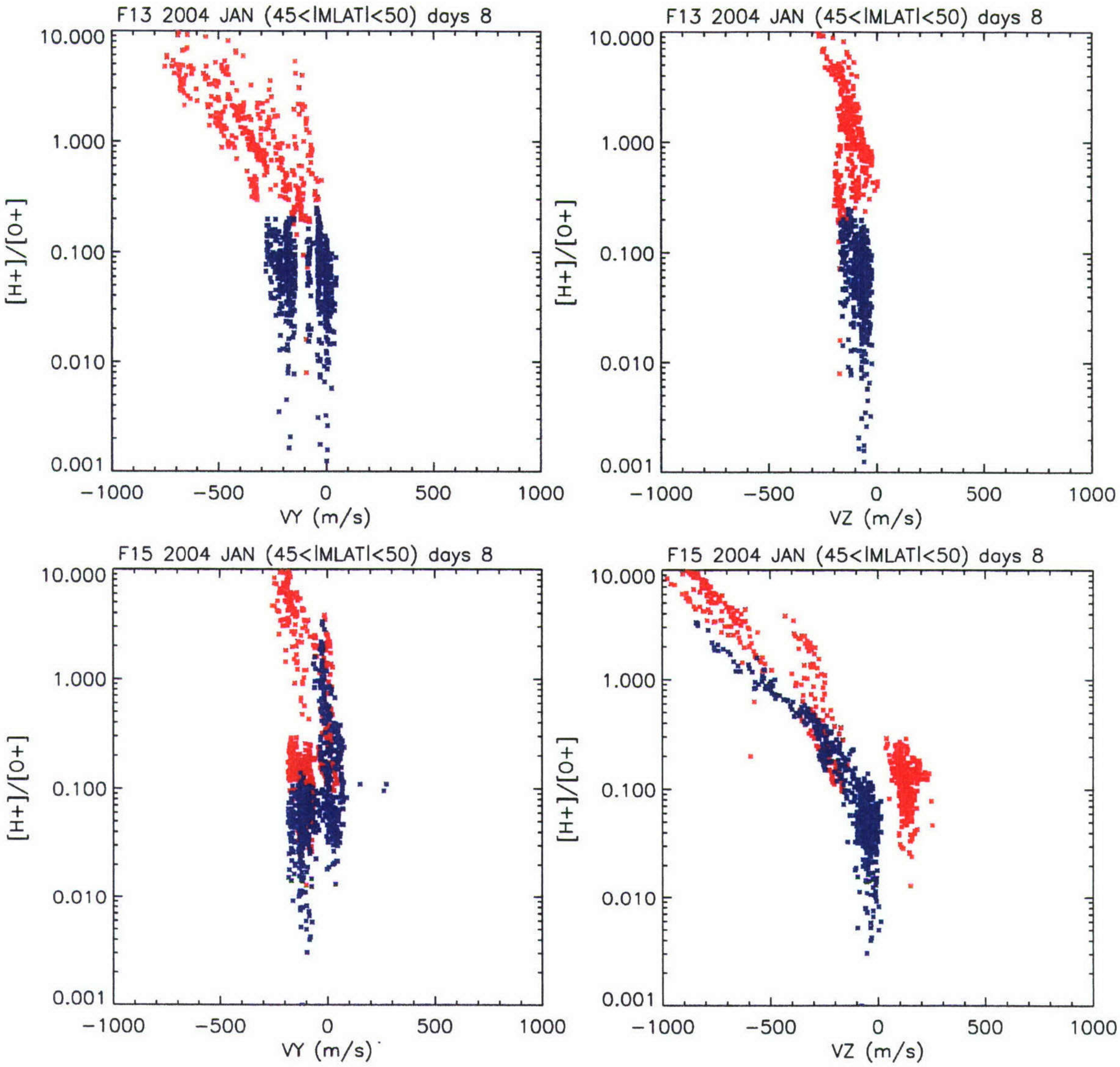

Figure 5. The ratio of H^+ to O^+ versus the ion drifts for F13 (top) and F15 (bottom) from January 2004 in the same format as Figure 1.

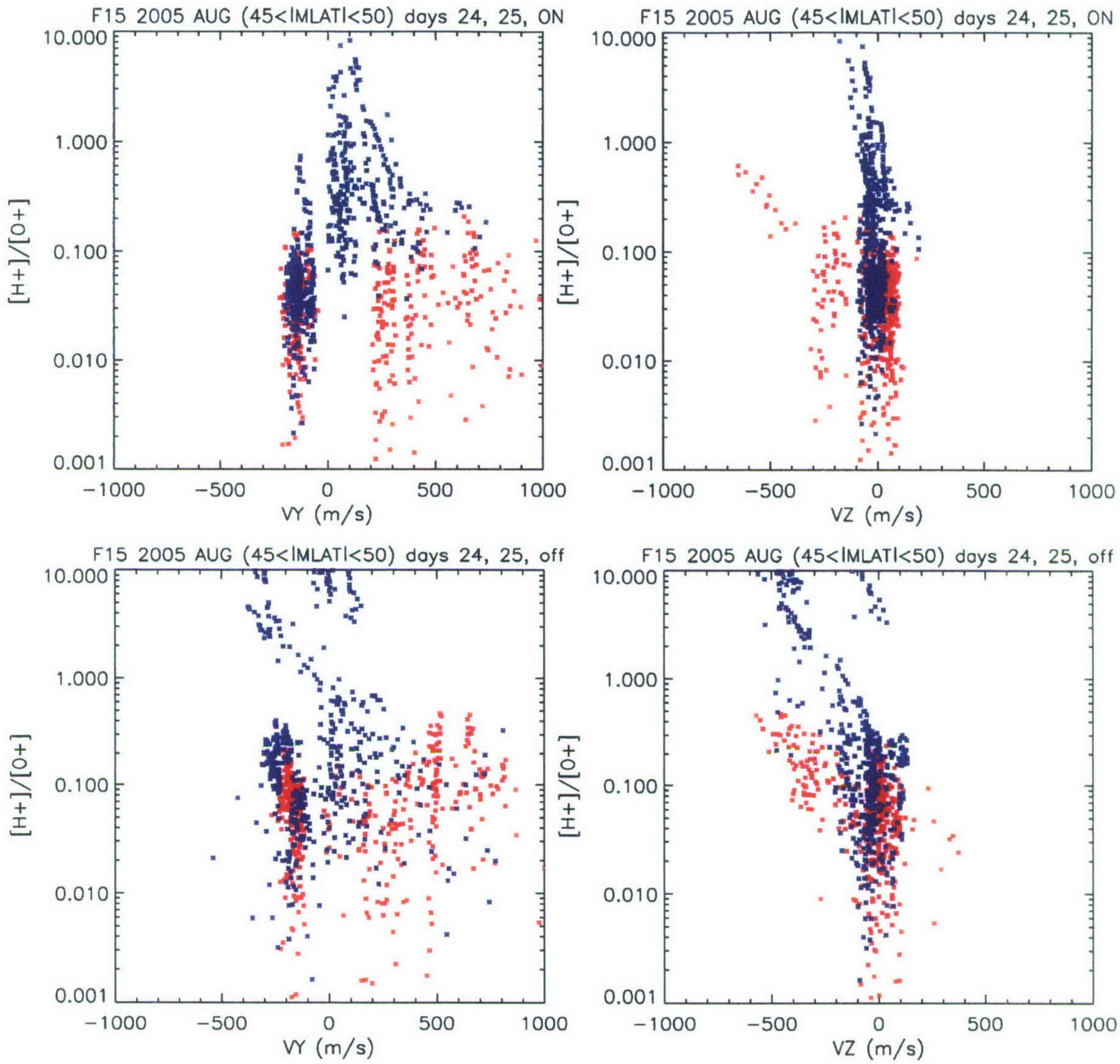

Figure 6. The ratio of H^+ to O^+ versus the ion drifts for F15 with the DREP on (top) and the DREP off (bottom) from October 2005 in the same format as Figure 1.

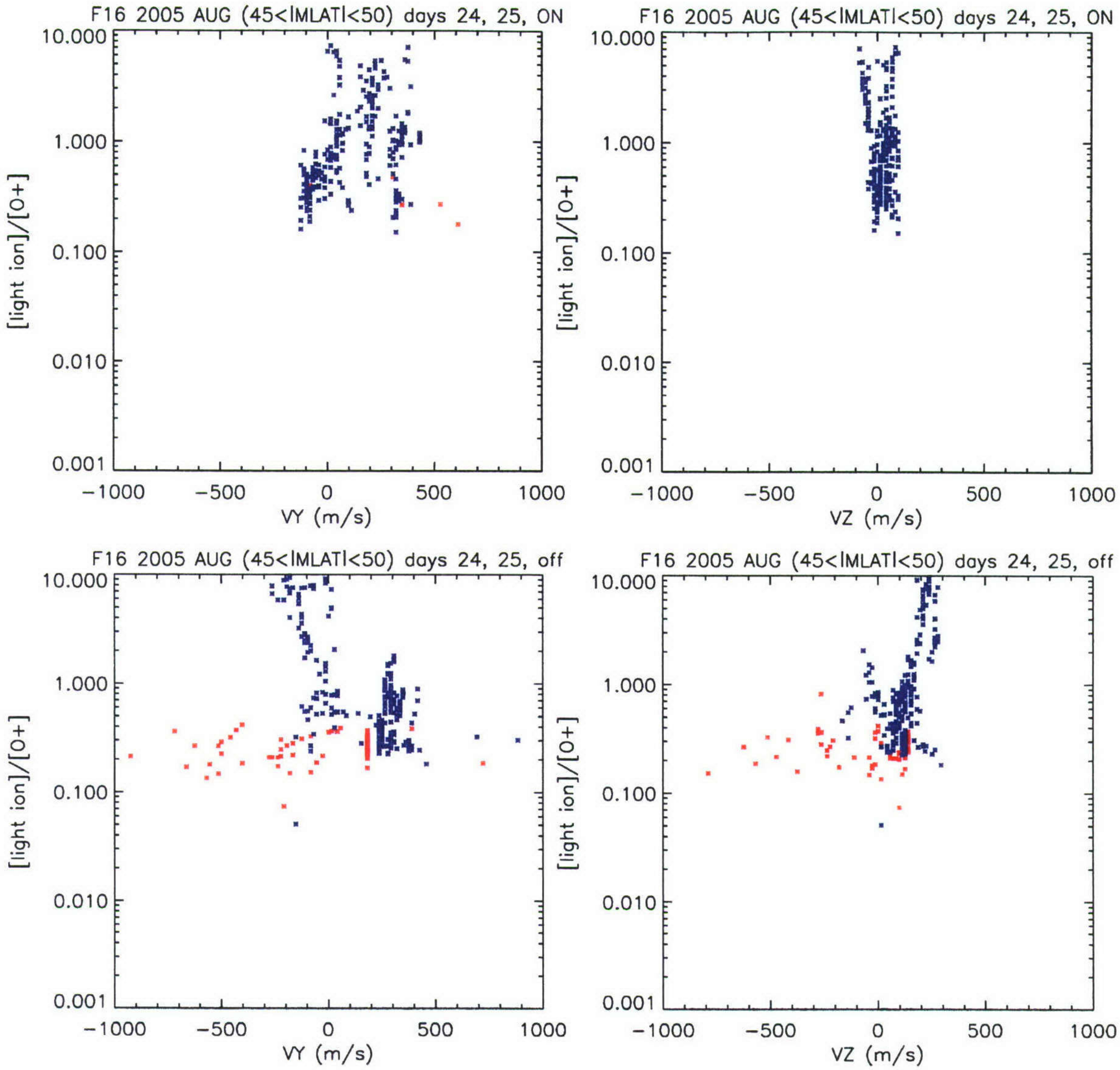

Figure 7. The ratio of H^+ to O^+ versus the ion drifts for F16 with the DREP on (top) and the DREP off (bottom) from October 2005 in the same format as Figure 1.

3. REMEDIATION OF SINGLE EVENT UPSETS

After the launch of F17, work was begun on the initial operations support for this spacecraft. The first task was the identification and remediation of single-event upsets occurring in the South Atlantic anomaly region. As was the case for F16, the main electronics package on F17 is apparently susceptible to single-event upsets induced by high-energy particle impacts, generally occurring in regions where such particles are often present. A command "reset" re-enables the sensor functions, and the ground command sequences have been reprogrammed to execute the "reset" command during the equatorial crossings of each orbit. While there may be brief data outages after a single-event upset, this command-level fix automatically restores instrument functionality. Evaluation of this fix has been on-going throughout the year and to date has proven to be functionally adequate.

4. SSIES-3 PROCESSING SOFTWARE

Work began in this period on the development of ground software designed to routinely process the raw F17 data from all the sensor heads and produce files of geophysical data records. As part of this effort, we are inspecting and evaluating the geophysical data produced by the on-board processing algorithms and comparing these results to those produced by the ground software. Initial efforts concentrated on reading and decoding the raw sensor data provided to UTD by AFRL into engineering units (e.g., currents and voltages). Determination of cross-track drifts from the DM and ion densities from the SM followed.

A major part of the software effort concentrated on the development of more sophisticated and robust algorithms for the analysis of data from the retarding potential analyzer (RPA). During this year, the first RPA task was the construction of current-voltage curves (engineering units) from the raw data. Geophysical units are produced from the RPA by fitting these current-voltage curves to a theoretical function through the use of a least-squares fitting algorithm (Levenberg-Marquardt). The results of an initial evaluation using a simple set of fixed initial conditions indicated that the Levenberg-Marquardt algorithm was converging under a wider variety of environmental conditions for data from the SSIES-3 RPA than was the case for the corresponding SSIES-2 instruments. In particular, it appears that the non-uniform distribution of retarding voltages chosen for use on the SSIES-3 RPA has allowed improved determination of the light ion (H^+ and He^+) concentrations over an increased range of ambient ion density. The improved convergence of the fitting algorithm gives us more confidence in the accuracy of the calculated geophysical parameters. These RPA measured geophysical parameters include total ion density, ion temperature, sensor potential with respect to the ambient plasma, ram component of ion velocity, and ion composition.

Next, the algorithm was improved to better handle cases where the ionosphere has a high concentration of light ions (H^+ and He^+). A preliminary output feedback algorithm was implemented to identify and correct cases where the initial analysis had not functioned correctly. The output feedback algorithm was improved to identify and correct cases where the initial analysis did not function correctly. Evaluation of the results of the least-squares fitting algorithm has continued through processing and examination of multiple orbits of raw data. Software was written toward the end of this contract period to allow processing of large amounts of SSIES-3 data in a "production mode." This has allowed larger amounts of preliminary data files of geophysical records thus produced from F16 and F17 to be placed on the in-house DMSP website for evaluation by UTD scientists.

In the third quarter of this contract, the construction of data reduction software for the plasma plate was initiated. Work remains to be done on this algorithm before reliable electron temperatures are produced from this sensor.

Figure 8 presents sample results using the current analysis software for data from the RPA, SM, electron sensor, and DM for one complete orbit of F17 on day 100 of

2007. The top panel shows the electron temperature (T_e) from the electron sensor as calculated by the on-board algorithm (dotted line). The solid line in this panel is the RPA-derived ion temperature (T_i). These ion temperatures appear to be generally well-determined in most locations with a couple of exceptions. The first is in the northern hemisphere auroral zones (i.e., ~1434 UT) where plasma conditions are rapidly varying on a spatial/temporal scale that precludes seeing a stable current-voltage curve over the one-second period necessary for the RPA to make a complete measurement. The second area of problems is the southern hemisphere high-latitude region where there exist both regions of rapidly changing plasma conditions and regions of very low (<$5x10^2$ cm^{-3}) plasma density in which the RPA does not function well. The second panel contains the RPA-determined ram (v_x) component of the plasma drift. A second offset smoothed trace is included to help visualize general trends in the data. Note the extended period of zero drift in the middle of the orbit. This is a region of almost pure light ions (no O^+). In such conditions, the Levenberg-Marquardt algorithm is unable to differentiate between variations in the ram velocity and variations in the sensor potential with respect to the plasma. As such regions occur primarily at low latitude where the ram component of the ion velocity is generally very low, we set v_x=0 and solve for the value of the spacecraft potential. Otherwise, the determination of v_x shows quality problems in the same areas as T_i. The center panel shows horizontal cross-track (solid line, v_y) and vertical (dashed line, v_z) velocities measured by the DM. The northern high-latitude region shows the pattern of sunward convection in the auroral zones and anti-sunward convection over the polar caps indicative of a two-cell convection pattern commonly present during times of a southward interplanetary magnetic field. The DM also functions poorly during the low-density conditions present in the southern hemisphere. The fourth panel shows the RPA calculated sensor potential relative to the plasma. A smoothed offset trace is also presented. The bottom panel gives the total ion density from the RPA (solid line), light ion (H^+ plus He^+) density (dotted line) from the RPA, and the total ion density from the SM (dashed line). The total ion density measurements are generally of good quality except in the active low-density southern hemisphere region. The reason for the apparent difference observed between RPA and SM derived density during the period of high light ion density is being investigated.

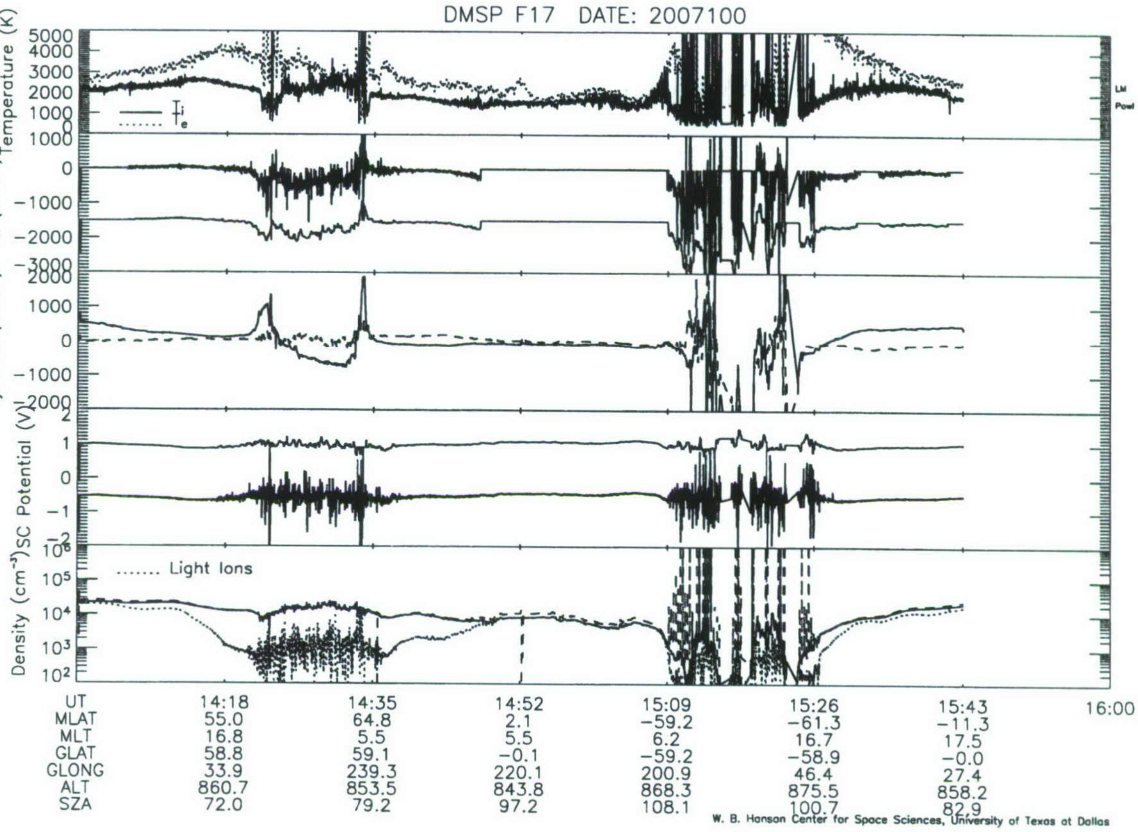

Figure 8. Summary plot of plasma parameters from the RPA, DM, electron sensor, and SM on DMSP F17. The top panel shows the ion temperature (solid line) and electron temperature (dotted line). The next panel shows the ram ion drift (v_x) and a smoothed offset trace to show general trends. The center panel shows horizontal cross-track (solid line, v_y) and vertical (dashed line, v_z) velocities. The fourth panel gives the sensor potential and a smoothed offset trace. The bottom panel gives the ion density from the RPA (solid line), light ion (H^+ plus He^+) density (dotted line), and the ion density from the SM (dashed line).

5. MISCELLANEOUS TASKS PERFORMED

During this period, support was provided for the development at UTD of the SSIES-3 ground-support equipment (GSE). An investigation was conducted on an apparent main electronics package (MEP) temperature anomaly that was reported by the Air Force and the anomaly was determined to be a single event upset. Maintenance was performed on the DMSP data website, and preparations were begun for the hosting of the DMSP data website to be changed to a computer controlled by the UTD Information Resources department in order to meet new UTD security requirements. UTD has continued to provide support services to AFRL as requested during this period.

6. WORK PLANNED FOR THE NEXT PERIOD

The University of Texas at Dallas will continue to develop and improve the F17 ground data analysis software and also inspect and compare the results of the on-board algorithm with that of the ground software. Development will continue on the RPA processing software with improvements to the initial input parameters and refinement of the output feedback algorithm to identify and correct cases where the initial analysis had not functioned correctly. A quality flag algorithm similar to that used on SSIES-2 will be developed and implemented. We will improve the plasma plate software and begin the development of the electron sensor data processing software. We will work to identify and correct isolated cases of failure in the data processing software.

Studies of the dependence of ion drift on the sensor plane potential suggest that the orientation of the satellite conducting surfaces with respect to the sun may play a role. We will investigate this possibility with a goal of improving the data quality in future generations of geophysical parameters.

The hosting of the DMSP data website will be changed to a computer controlled by the UTD Information Resources department in order to meet new UTD security requirements. We will continue to provide support to AFRL to help enable them to process F17 data.

7. SCIENTISTS AND ENGINEERS CONTRIBUTING TO THIS RESEARCH

The following are scientists and engineers that contributed to this research:

- W. R. Coley	Research Scientist
- R. A. Heelis	Principal Investigator
- M. D. Perdue	Research Engineer/Scientist
- R. A. Power	Project Supervisor
- P. C. Anderson	Research Scientist/Professor